METHODS OF ASSESSING HERBAGE FEEDING VALUE

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SUMMARY

Methods for measuring herbage feeding value have been classified into three main groups — intake; apparent digestibility; and rumen volatile fatty acid proportions. Each group has been subdivided into direct measurement methods using animals and indirect techniques using some simple characteristic of the feed or faeces. The accuracy and limitations of the various techniques are discussed.

INTRODUCTION

FOR SEVERAL decades plant breeders have been introducing new herbage species and varieties that are better than their predecessors in terms of their dry matter production and the annual distribution of this dry matter.

In recent years there have been numerous publications each describing some new nutritional assessment which will readily answer the problems of the plant breeder, herbage and animal agronomist. However, all these techniques measure only a limited aspect of herbage feeding value and usually their accuracy leaves much to be desired. The aim of this paper is to provide a skeleton of the problem of nutritional evaluation on to which these techniques are fitted.

In most cases poor feeding value of herbage is associated with either a protein or an available energy deficiency, although the possibility of mineral or vitamin imbalances or deficiencies can never be overlooked. With grazed herbage in temperate climates it is now believed that available energy is the factor controlling feeding value (Crampton, 1957) provided the herbage is not so good as to exceed the animals' productive potential (Ivins *et al.*, 1958).

The production of a grazing animal at a particular stage of growth or lactation is controlled by the quantity of Net Energy eaten. This quantity depends on two factors, the quantity of herbage eaten and the Net Energy content of each unit of feed. In any system of assessing herbage feeding value it is therefore necessary to measure both factors.

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Accurate methods of measuring both feed intake and its Net Energy content are available for animals kept indoors, but for field experiments indirect methods have to be used. Most of these indirect methods rely on regression equations which are derived from controlled indoor animal trials and then applied in the field where feeding value is estimated from some simple laboratory measurement.

This paper will describe some of the direct methods of measuring feeding value and the suggested indirect approaches, together with a few comments on their accuracy. Some research workers will not agree with the classification employed but it is presented because it might reduce the current confusion in this topic. Table 1 shows the interrelationship of the techniques to be discussed.

TABLE 1: CLASSIFICATION OF HERBAGE EVALUATION METHODS

INTAKE OF NET ENERGY

METHOD	(1) INTAKE	(2) NET ENERGY	
		(2A) DIGESTIBILITY	(2B) RUMEN V.F.A. PROPORTIONS
Direct	Indoor trial.	Indoor trial.	Rumen fistulated animal.
Indirect	(I) Faecal techniques — Chromic oxide plus faecal component regression equations. Table 2. (II) Intake/digestibility relationships.	(I) Feed composition regression equations. Table 3. (II) Faecal composition regression equations. Table 2. (III) Leaf lamina percentage. (IV) Date of cutting. (V) *In vitro* fermentation methods.	Herbage soluble carbohydrate content.
	(3) INTAKE DIGESTIBLE ENERGY		
Direct	From direct methods 1 and 2A above.		
Indirect	(I) From indirect methods 1 and 2A above. (II) 12 hour cellulose digestion *in vitro* (N.V.I.)		

1. DRY MATTER INTAKE
(See Section 1 of Table 1)

DIRECT METHODS

Because of the errors associated with the measurement of herbage intake by cutting techniques, many intake studies are now conducted with cut grass fed in the fresh, frozen or dried state to animals in stalls (Blaxter *et al.*, 1961; Hutton, 1962). Owing to its low error, the indoor trial is the standard by which all other techniques should be tested, for, if techniques are found to be inaccurate under controlled indoor conditions, then it is very unlikely that they will be any better in the field.

INDIRECT METHODS

Faecal Techniques

In 1935 Garrigus and Rusk suggested that the dry matter intake of grazing animals could be estimated from the quantity of faecal dry matter produced by the grazing animal and the dry matter digestibility of the grazed herbage.

$$\text{D.M. Intake} \equiv \text{Faecal D.M.} \times \frac{100}{100 - \text{D.M. Digestibility}}$$

where D.M. = Dry Matter

Faeces production can be measured directly by the use of collecting bags attached to the animal, but the use of these bags is laborious and could influence herbage consumption. Indirect methods based on an added indigestible tracer are now widely employed. Chromic oxide was first used for this purpose at Ruakura Animal Research Station and is still the most commonly used external indicator although others have been tried — *e.g.*, radioactive chromic oxide, monastral blue, and polyethylene glycol.

Although these external tracers overcome the difficulties of total collection, they introduce errors of their own owing to incomplete recovery of the tracer and difficulties in obtaining representative samples of the faeces because of diurnal fluctuations in the excretion of the tracer (Brisson, 1961; Corbett, 1961).

In the original Garrigus and Rusk (1935) method, the digestibility of the grazed herbage was determined with stalled animals fed grass cut from an area adjacent to that being grazed. This method was laborious and did not

eliminate errors due to selective grazing and differences in level of feeding. In 1947, Lancaster found that the nitrogen percentage of the faeces of sheep fed indoors was related to the digestibility (or feed/faeces ratio) of the herbage eaten. Using this relationship it became possible for the first time to estimate the digestibility of selectively grazed herbage from a simple faecal nitrogen analysis. Following this breakthrough other regression equations were derived in which digestibility was related to other faecal components. A selection of these is given in Table 2.

Although these indirect faecal index regression equations appeared to overcome the error caused by selective grazing, they introduced errors of their own, as the relationship between faecal composition and digestibility is not causal in origin.

Raymond *et al.* (1954) showed that regression equations based on faecal chemical composition had large standard errors of the estimate of digestibility but suggested that the error to be applied in the field would be considerably reduced if large numbers of animals were used. A similar conclusion was drawn by other workers. However, it has recently been shown (Minson and Raymond, 1958; Greenhalgh and Corbett, 1960; Minson and Kemp, 1961) that one of the major sources of error in these equations is not animal variation or analytical error but true differences in the nitrogen percentage of the faeces produced from different herbages having the same digestibility.

In recent years it has been suggested that to obtain a satisfactory accuracy it is necessary to use parallel indoor digestion trials on herbage cut from an area adjacent to that being grazed and to use these to calculate "local" regression equations. Even with this technique it is doubtful whether intake differences of less than 15% are statistically significant (*Research Techniques in use at the Grassland Research Institute,* 1962). Lambourne and Reardon (1962) found different regression equations for leaf and stem which suggests that even "local" regression equations are not as accurate as hoped. For a further consideration of the errors caused by applying equations derived indoors to field conditions see Corbett (1961) and *Research Techniques in use at the Grassland Research Institute* (1962).

Two other methods of estimating the digestibility of grazed herbage are available. The first is to use a naturally occurring plant tracer which is determined in samples of herbage grazed (or obtained via an oesophageal fistula) and in the faeces. Lignin, silica and chromogen(s) have all been

tried (Raymond, 1954). The other method is to determine the digestibility of a herbage sample obtained via an oesophageal fistula using one of the indirect laboratory methods described in the section dealing with Net Energy below.

Intake-Digestibility Relationships

It is generally recognized that ruminant appetite declines as grass becomes less digestible. Recently this relationship has been put on to a quantitative basis for sheep (Blaxter *et al.*, 1961) and cattle (Blaxter and Wilson, 1962). However, in this work only a few forages were used and these covered a wide range of apparent energy digestibilities. It would, therefore, be wrong to draw the conclusion that appetite can be accurately predicted simply from the apparent energy digestibility. It has been found that appetite for red clover is much higher than for timothy with a similar energy digestibility (Lloyd *et al.*, 1960) while for good quality grass having over 70% apparent organic matter digestibility Hutton (1962) found no relationship between intake and digestibility. More critical work appears necessary.

2. NET ENERGY CONTENT

(See Section 2 of Table 1)

The Net Energy content in each unit of feed is the proportion of the feed that is utilized by the animal and is measured by direct or respiration calorimetry. Both standard methods are laborious and expensive and techniques which measure only a component of Net Energy are widely used.

The most important factor influencing Net Energy is the content of apparent digestible energy, or more crudely the apparent dry matter or organic matter digestibility. Direct and indirect methods of measuring apparent digestibility will be considered in the next section. The problem of evaluating the products of digestion are considered in Section 2B.

2A. Apparent Digestibility

Direct Methods

The ideal method of measuring the apparent digestibility is "to give the experimental ration in exact quantities for long periods, in order to ensure that a 'steady state' of faecal excretion is reached, and then to collect the faeces excreted during a measured interval of time" (Blaxter *et al.*, 1956). The apparent digestibility is calculated as the percentage difference between the quantity of food eaten and faeces

TABLE 2: REGRESSION EQUATIONS FOR PREDICTING DIGESTIBILITY (OR FEED-FAECES RATIO) FROM FAECAL COMPOSITION

Faecal Component	*Equation*	*Correlation Coefficient*	*Standard Error of Estimate*	*Author*
Nitrogen	$Y = 0.97N + 1.112$		—	Lancaster, 1950
	$Y = 0.97N + 1.02$		C.V. 9.1	Lancaster, 1954
	$D(OM) = 44.85 + 7.947N$		±3.4*	Raymond *et al.*, 1954
	$Y = 10.34 \log N - 1.33$		C.V. 8.4	Kennedy *et al.*, 1959
Crude fibre	$D(OM) = 93.42 - 0.6582F$		±3.4*	Raymond *et al.*, 1954
Normal acid fibre	$D(OM) = 124.22 - 1.058F$	−0.932	±2.65*	Raymond *et al.*, 1955
Methoxyl	$D = 118.15 - 17.61M$	−0.974		Richards & Reid, 1952
Chromogen(s)	$D(DM) = 32.74 + 0.0168C + 8.47 \log C$	0.96	±0.44	Reid *et al.*, 1952
	$D(OM) = 60.10 + 0.0188C$		±3.8*	Raymond *et al.*, 1954
	$D(DM) = 38.75 \log C - 0.0046C - 32.12$		±2.9	Smith & Reid, 1955
	$Y = 3.81 \log C + 2.24$		C.V. 10.6	Kennedy *et al.*, 1959

D — Apparent digestibility.
SE — Starch Equivalent.
DM — Dry Matter.
OM — Organic Matter.
E — Energy.
Y — Feed faeces ratio.
N, F, M, C, L — Concentration of respective component.
C.V. — Coefficient of variation.
C.P. — Crude Protein.

* Calculated by writer.

TABLE 3: REGRESSION EQUATIONS FOR PREDICTING DIGESTIBILITY FROM CHEMICAL COMPOSITION OF FEED

Herbage Component	*Equation*	*Correlation Coefficient*	*Standard Error of Estimate*	*Author*
Nitrogen	$SE = 0.6886$ C.P. $+ 47.971$	—	—	Watson & Horton, 1936
	$D(OM) = 59.7 + 5.2N$	—	—	Minson & Kemp, 1961
Crude fibre	$D(OM) = 90.1 - 0.879F$	—	—	Axelsson, 1938
	$D(OM) = 92.61 - 0.96F$	— 0.944	5.21	McMeekan, 1943
	$D(OM) = 84.69 - 0.86F$ (cattle)	—	—	Hallsworth, 1949
	$D(OM) = 87.45 - 0.63F$ (sheep)	—	—	Hallsworth, 1949
	$D(OM) = 100.62 - 1.101F$	—	4.28*	Griffith & Thomas, 1955
Normal acid fibre	$D(OM) = 121.85 - 1.251F$	—	4.31*	Griffith & Thomas, 1955
Lignin	$D(E) = 113.1 - 5.31L$ (Timothy)	—	—	Phillips & Loughlin, 1949
	$D(E) = 96.5 - 3.39L$ (lucerne)	—	—	Phillips & Loughlin, 1949
	$D(OM) = 95 - 4.10L$ (steers)	—	—	Forbes & Garrigus, 1950
	$D(OM) = 98 - 5.32L$ (sheep)	—		
	$D(OM) = 73.22 - 2.063L$	—0.419	—	Common, 1952
	$D(DM) = 99.8 - 6.11L$	—	±2.8	Sullivan, 1959
Methoxyl	$D(DM) = 83.35 - 10.478M$	— 0.724	±3.13	Richards *et al.*, 1958

* Calculated by writer.

See foot of Table 2 for explanation of symbols.

produced. Since grass cut daily will be changing in composition, it is difficult to obtain a "steady state" and hence reliable digestion coefficients with "continuous" digestion trials, although through lack of equipment this method often has to be used. The only satisfactory way of overcoming this difficulty is to cut the herbage at the desired stage of growth and conserve in the frozen or dried state. In indoor trials faecal production is usually measured by total collection, but chromic oxide is sometimes used as an indirect method in the same way as described for grazing animals in the section on dry matter intake. (It is important to note that when chromic oxide is used in experiments with grass fed animals indoors only faeces production is measured and herbage digestibility can be determined only if herbage intake is also measured.)

Indirect Methods

Herbage has been analysed for many components as a subject in its own right, but in the last two decades attempts have been made to relate these analyses to the results of digestion trials. As a result of this work, many regression equations have been developed which can be used to predict herbage feeding value.

Herbage Nitrogen

Watson and Horton (1936) suggested that the Starch Equivalent of a herbage could be estimated from its crude protein content. Despite the warning given as to the limitation of this relationship, it has since been widely used in the design and interpretation of experiments without any consideration of the inherent errors. Raymond *et al.* (1955) reported that the correlation between organic matter digestibility and herbage nitrogen was only 0.48. Subsequent work showed that this poor agreement was partly caused by the existence of different relationships for lucerne and grass (Minson and Brown, 1959) and for grasses produced at different times of the year (Minson and Kemp, 1961).

Fibrous Components

Regression equations have also been derived relating apparent digestibility (dry matter or organic matter) to crude fibre, normal acid fibre, lignin and methoxyl content of the herbage (see Table 3). All these regression equations had standard errors of the estimates greater than 2.8 digestibility units. Of particular interest is the work of Sullivan

(1959) who showed that the large standard error was caused by the inclusion of different grass species each having a different regression equation.

Date of Cutting

As a result of 94 digestion trials in the United States, Reid, Kennedy *et al.* (1959) suggested that the digestibility of first growth herbage could be estimated regardless of species with an accuracy of ± 1.68 units simply from their cutting dates. Taking this result to its logical conclusion, suggests there is little scope for improving the feeding value of first cuts by plant breeding and that the leafier, late-flowering varieties have the same feeding value as earlier stemmy material. Subsequent work in England (Minson *et al.*, 1960) showed that different grass species at the same stage of growth could have differences in apparent organic matter digestibilities as large as 6% while a late-flowering ryegrass was 16% more digestible than an early variety cut on the same day.

Leaf Lamina Percentage

Leafiness of herbage has always been assumed to be synonymous with feeding value and leafiness has been used as a selection criterion by plant breeders. Reid, Kennedy *et al.* (1959) found that dry matter digestibility (D) of first growths were highly correlated ($r=0.95$) with leaf percentage (L) and their relationship was expressed by the equation $D=0.4L-40.8$. This relationship did not apply to pasture regrowth. However, in England it was found that cocksfoot was 6% less digestible than ryegrass at similar stages of growth, although cocksfoot had a higher leaf percentage. (Minson *et al.*, 1960.)

In vitro *Fermentation Techniques*

Walker (1959) and Reid, Shelton *et al.* (1959) found that *in vivo* dry matter digestibilities could be estimated by incubating dried herbage with rumen liquor. Subsequent work by Tilley *et al.* (1961) showed the method to be unsatisfactory with high protein herbages unless the initial rumen fermentation was followed by pepsin digestion. Using this double stage *in vitro* fermentation technique, the correlation coefficient between *in vitro* and *in vivo* results was $+0.98$ and the standard error of the estimate of the regression equation ± 2.01. Using a similar technique, Alexander and McGowan (1961) found a correlation coefficient of $+0.97$ and a regression equation with a ± 2.34 standard error of estimate.

2B. Rumen V.F.A. Proportions

Digestibility trials measure only the proportion of the feed that disappears from the digestive tract and it has been recognized for many years that nutrients digested from different feeds vary in their production value. One of the major products of digestion are volatile fatty acids and Armstrong *et al.* (1957) demonstrated that acetic acid was less efficiently utilized for fattening than propionic and butyric acids. The efficiency for milk production of the various acids remains to be determined although it is known that low acetic acid production leads to low milk fat percentages (Shaw, 1959).

When evaluating herbages, volatile fatty acid proportions are often determined in samples of rumen contents taken through a stomach tube or rumen fistula. This can be described as the direct method. Tilley *et al.* (1961) found a relationship between the soluble carbohydrate content of herbage and the molar proportion of rumen propionic acid. However, subsequent work showed that the correlation coefficient for this relationship was only 0.75 and that other factors affect this indirect method (Terry and Tilley, 1962).

3. Intake of Digestible Energy

(See Section 3 of Table 1)

With herbage feeding value apparently being markedly affected by three factors — intake, apparent digestibility, and volatile fatty acid proportions — there is obviously a need for some single figure which can combine all three measurements, enabling herbages to be ranked in their order of expected animal productivity. No attempt has yet been made to combine all three measurements but the product of intake and apparent digestibility has been used for many years. American results are usually quoted as T.D.N. per animal or 100 lb body weight. New Zealand has used the term intake of digestible organic matter, while recently Blaxter (1961) quoted results as digestible calories per unit metabolic size (or function of body weight).

Recently a new method of expressing digestible nutrient intake has been introduced called the Nutritive Value Index (Crampton *et al.*, 1961).

$$\text{N.V.I.} = \frac{100 \times \text{Appetite}}{80 \times \text{Metabolic size}} \times \text{Energy digestibility percentage}$$

This differs in two ways from the simple expression of Blaxter (1961):

(1) The N.V.I. system uses a standard feed which by definition has a value of 80 g per unit metabolic size. Blaxter's system uses no arbitrary standard.

(2) When calculating N.V.I., the energy digestibility percentage is used instead of the quantity of digestible energy per unit of feed. Therefore the N.V.I. system cannot take into account differences in the energy content of each gram of digested herbage.

It appears that, despite being more complex, the N.V.I. system is a less efficient method of describing overall feeding value than digestible energy per unit metabolic size.

Direct Methods

By combining separate direct measurements of intake and digestibility, intake of digestible herbage is readily calculated.

Indirect Methods

Where herbage intake is being measured from the quantity of faeces and the digestibility of the herbage (Section 1), then intake of digestible nutrients can be estimated by subtracting the weight of faeces organic matter produced from the estimated organic matter eaten (Lancaster, 1954). Recently Donefer *et al.* (1960) have reported a relationship between N.V.I. and 12-hour cellulose digestion *in vitro* and suggested this could be used for predicting N.V.I. Owing to the similarity between N.V.I. and "digestible energy per unit metabolic size" it should be possible to calculate relationships between the latter and 12-hour cellulose digestion.

DISCUSSION

In this paper an attempt has been made to classify some of the many herbage evaluation techniques into those measuring intake, Net Energy content, and intake of digestible energy. Each group has been subdivided into direct measurements with stall-fed animals and indirect methods which usually rely on a previously derived regression equation relating a direct measurement with animals to some more readily determined character of the feed or faeces. In this paper a comprehensive review was impossible and only some of the limitations of the various techniques have been considered.

Although animals show individual variation in their digestive efficiency and intake, the direct measurement with animals under controlled indoor conditions appears to be the only standard for developing indirect techniques and

studying their accuracy. This may be obvious, but it is surprising how often one indirect method is used as the standard when studying another indirect technique. Even more surprising is the common belief that indirect methods based on regression equations are as accurate or even more accurate than direct measurement with animals. The reason generally advanced for this belief is that once the regression equation is calculated the only error involved in making a prediction from the regression is that associated with analytical error, despite statistical evidence to the contrary (Snedecor, 1956).

Although a relationship between a direct animal measurement (*e.g.*, apparent digestibility) and some indirect measurement (*e.g.*, herbage nitrogen) may be highly significant, the relationship is never perfect as indicated by standard errors (S.E.) of estimate of the regression equations in Tables 2 and 3.

As the name suggests, the S.E. of estimate has to be applied to any estimation made from the regression equation, although many equations are published without this statistic. (More correctly the larger S.E. of prediction should be applied which takes into account the standard error of the regression coefficient (Raymond *et al.*, 1954).) If the S.E. of estimates shown in Tables 2 and 3 are applied, it is found that the results in most experiments are not statistically significant. The natural tendency has therefore been to overlook the necessity of applying any error to the estimates, claiming that the large S.E. of estimate are caused by variation in the animals used in the direct animal determination.

In recent years there have been a number of studies of the cause of the deviations from equations relating digestibility to both herbage and faecal chemical components. In one study of a digestibility/faecal nitrogen regression equation with a ± 2.86 S.E. of estimate it was shown that 90% of the variation was caused by herbage differences and only 10% by animal, analytical and random errors (Minson and Raymond, 1958). More recently it has been found that regression equations derived from a wide range of feeds can be broken down into a number of equations limited to specific herbage species (Sullivan, 1959) or month of cutting (Minson and Kemp, 1961). It has also been found that regression equations based on a single feed have S.E. of estimates of only about ± 1 (Minson, 1958; Corbett, 1961).

These results suggest that animal and analytical variation is only a small component of the S.E. of estimate of these

regression equations and that when used the standard error of the estimate must always be applied.

The necessity of applying the S.E. of estimate to all predictions is well illustrated by the following example. Cocksfoot and ryegrass cut on the same day contained 2.40% and 2.14% nitrogen respectively (Minson *et al.*, 1960). The apparent organic matter digestibilities predicted from a regression equation restricted to the month of May (Minson and Kemp, 1961) were 76.5% and 75.5% respectively, suggesting that cocksfoot was more digestible than ryegrass. However, in sheep digestion trials the cocksfoot was 5.3% less digestible. Only when the published standard error of the estimate of ±3.96 was applied to the predicted digestibility was the reason for the discrepancy apparent (Fig. 1).

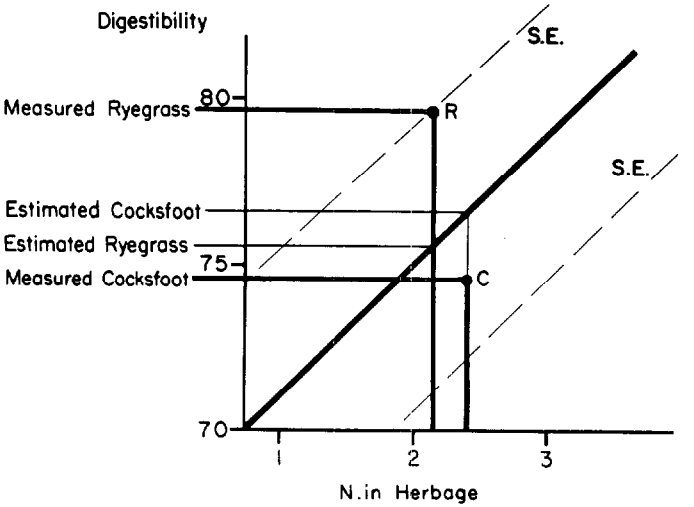

Fig. 1: Demonstration of the need to apply standard errors of the estimate to predictions of digestibility from a chemical constituent of feed or faeces.

At the risk of labouring a point which is obvious to most it must be emphasized that failure in the past to accept this simple idea has led to very misleading conclusions. For many years it was thought in England that cocksfoot had a higher starch equivalent than ryegrass simply because it had a higher nitrogen content, despite the observations of farmers to the contrary.

The usefulness of any indirect technique of measuring herbage feeding value will depend both on its accuracy and on the expected differences between feeds. The largest interspecies herbage difference recorded is probably the 6%

difference between cocksfoot and ryegrass reported above, but of the indirect digestibility methods recorded only the *in vitro* fermentation technique of Tilley *et al.* (1961) is sufficiently accurate to measure this difference with statistical significance. Cooper (1962), using an *in vitro* fermentation method, studied the variability in digestibility of both clones and families of ryegrass and cocksfoot. Clonal and family differences of up to 20% and 10% respectively were recorded but since the grasses were cut on the same day and not according to stage of growth it is difficult to assess what differences are likely to occur at the same stage of growth and hence the accuracy required of any digestibility estimate. Further work is needed before the value of the indirect methods in plant breeding problems can be accurately assessed.

CONCLUSION

In future work on the development and use of indirect methods of evaluating herbage the following suggestions might prove helpful:

(1) Whenever an indirect method is being developed, its accuracy must be determined by comparison with a direct animal measurement and the standard error of the estimate calculated.

(2) When using regression equations to predict herbage feeding value, the standard error of the estimate (preferably S.E. of prediction) must be applied to all estimates unless it can be proved that a smaller error is valid.

(3) Since large errors are associated with most indirect methods of evaluation, any results obtained by their use should be regarded with caution.

(4) Wherever small differences are expected, direct methods of evaluation with animals should be used.

REFERENCES

ALEXANDER, R. H., MCGOWAN, M. (1961): *J. Brit. Grassl. Soc., 16*: 275.
ARMSTRONG, D. G., BLAXTER, K. L., GRAHAM, N. MCC. (1957): *Proc. Brit. Soc. Anim. Prod.*, p. 3.
AXELSSON, J. (1938): *Z. Tierernährung., 10*: 238.
BLAXTER, K. L. (1961): *Proc. 8th Internat. Grassl. Congr.*, p. 479.
BLAXTER, K. L., GRAHAM, N. MCC., WAINMAN, F. W. (1956): *Brit. J. Nutr., 10*: 69.
BLAXTER, K. L., WAINMAN, F. W., WILSON, R. S. (1961): *Anim. Prod. 3*: 51.
BLAXTER, K. L., WILSON, R. S. (1962): *J. Brit. Soc. Anim. Prod., 4*: 351.
BRISSON, G. J. (1961): *Proc. 8th Internat. Grassl. Congr.*, p. 435.
COMMON, R. H. (1952): *Proc. 6th Internat. Grassl. Congr.*, p. 1254.
COOPER, J. P. (1962): *Rep. Welsh Pl. Breed. Sta. 1961*, p. 145.
CORBETT, J. L. (1961): *Proc. 8th Internat. Grassl. Congr.*, p. 438.
CRAMPTON, E. W. (1957): *J. Anim. Sci., 16*: 546.

CRAMPTON, E. W., DONEFER, E., LLOYD, L. E. (1961): *Proc. 8th Internat. Grassl. Congr.*, p. 462.
DONEFER, E., CRAMPTON, E. W., LLOYD, L. E. (1960): *J. Anim. Sci., 19*: 545.
FORBES, R. M., GARRIGUS, W. P. (1950): *J. Anim. Sci., 9*: 531.
GARRIGUS, W. P., RUSK, H. P. (1935): *Proc. Amer. Soc. Anim. Prod.*, p. 75.
GREENHALGH, J. F. D., CORBETT, J. L. (1960): *J. Agric. Sci., 55*: 371.
GRIFFITH, G. ap., THOMAS, D. C. (1955): *Agric. Progr. 30*: 124.
HALLSWORTH, E. G. (1949): *J. agric. Sci., 39*: 254.
HUTTON, J. B. (1962): *Proc. N.Z. Soc. Anim. Prod., 22*: 12.
IVINS, J. D., DILNOT, JEAN, DAVISON, J. (1958): *J. Brit. Grassl. Soc., 13*: 23.
KENNEDY, W. K., CARTER, A. H., LANCASTER, R. J. (1959): *N.Z. J. Agric. Res., 2*: 627.
LAMBOURNE, L. J., REARDON, T. F. (1962): *Nature* [Lond.], *196*: 961.
LANCASTER, R. J. (1947): *Proc. N.Z. Soc. Anim. Prod., 7*: 125.
———— (1950): *Proc. N.Z. Soc. Anim. Prod., 10*: 45.
———— (1954): *N.Z. J. Sci. Tech., 36A*: 15.
LLOYD, L. E., CRAMPTON, E. W., DONEFER, E., BEACOM, S. E. (1960): *J. Anim. Sci., 19*: 859.
MCMEEKAN, C. P. (1943): *N.Z. J. Sci. Tech., 25A*: 152.
MINSON, D. J. (1958): Ph.D. thesis, Reading University.
MINSON, D. J. BROWN, S. A. (1959): *11th Annu. Rep. Grassl. Res. Inst. Hurley, 1957–8*, p. 99.
MINSON, D. J., KEMP, C. D. (1961): *J. Brit. Grassl. Soc., 16*: 76.
MINSON, D. J., RAYMOND, W. F. (1958): *10th Annu. Rep. Grassl. Res. Inst. Hurley 1956–7*, p. 92.
MINSON, D. J., RAYMOND, W. F., HARRIS, C. E. (1960): *J. Brit. Grassl. Soc., 15*: 174.
PHILLIPS, T. G., LOUGHLIN, M. E. (1949): *J. agric. Res., 78*: 389.
RAYMOND, W. F. (1954): *J. Brit. Grassl. Soc., 9*: 61.
RAYMOND, W. F., JONES, E. C., HARRIS, C. E. (1955): *Agric. Progr., 30*: 120.
RAYMOND, W. F., KEMP, C. D., KEMP, A. W., HARRIS, C. E. (1954): *J. Brit. Grassl. Soc., 9*: 69.
RESEARCH TECHNIQUES IN USE AT THE GRASSLAND RESEARCH INSTITUTE, HURLEY (1962): *Bull. 45*, Comm. Bur. Pastures and Field Crops. Hurley, Berkshire, England.
REID, J. T., KENNEDY, W. K., TURK, K. L., SLACK, S. T., TRIMBERGER, G. W., MURPHY, R. P. (1959): *Agron. J., 51*: 213.
REID, J. T., WOOLFOLK, P. G., HARDISON, W. A., MARTIN, C. M., BRUNDAGE, A. L., KAUFMANN, R. W. (1952): *J. Nutr., 46*: 255.
REID, R. L., SHELTON, D. C., WELCH, J. A., JUNG, G. A. (1959): *J. Anim. Sci., 18*: 1537.
RICHARDS, C. R., REID, J. T. (1952): *J. Dairy Sci., 35*: 595.
RICHARDS, C. R., WEAVER, H. G., CONNOLLY, J. D. (1958): *J. Dairy Sci., 41*: 956.
SHAW, J. C. (1959): *Agron. J., 51*: 242.
SMITH, A. M., REID, J. T. (1955): *J. Dairy Sci., 38*: 515.
SNEDECOR, G. W. (1956): *Statistical Methods* 5th edn., Iowa State College Press, p. 135.
SULLIVAN, J. T. (1959): *J. Anim. Sci., 18*: 1292.
TERRY, R. A., TILLEY, J. M. A. (1962): *14th Annu. Rep. Grassl. Res. Inst., Hurley, 1960–61*, p. 58.
TILLEY, J. M. A., DERIAZ, R. E., TERRY, R. A. (1961): *Proc. 8th Internat. Grassl. Congr.*, p. 533.
WALKER, D. M. (1959): *J. Agric. Sci., 53*: 192.
WATSON, S. J., HORTON, E. A. (1936): *J. agric. Sci., 26*: 143.

DISCUSSION

PROFESSOR I. E. COOP: *Provided the animals outdoors were on the same ryegrass-white clover pasture as that cut and fed to the animals on indoor digestibility trial, and provided such a pasture, under continuous grazing, did not show marked monthly variations in the nitrogen/digestibility relationship (and our continuously grazed pastures do not show any such marked variation) would Dr Minson agree that the prediction of intake of the outdoor animals might not be as bad as his paper would lead us to believe?*

DR D. J. MINSON: The error of prediction should be much smaller where a "local" regression equation is used but selective grazing can introduce a large error due to the existence of different regression equations for leaf and stem (Lambourne and Reardon, 1962).

DR J. B. HUTTON: I should like to mention two points. First, it is important that indoor feeding trials simulate as far as possible field grazing conditions. Otherwise, regressions calculated from the former will underestimate errors of predicting intake in the field.

Secondly, Dr Minson has indicated that separate regressions of percentage digestibility on faecal nitrogen should be calculated for different herbage species. He has also shown that within particular swards different regressions can be calculated according to month of the year. The latter is in accord with the recommendations of Greenhalgh and Corbett (1960) for different cuts of the same sward. On the other hand, Lancaster (1954) found with paspalum, pampas grass, and a ryegrass-white clover sward, the latter cut at several stages of growth, that a single linear regression of feed O.M./faeces O.M. ratio on faecal nitrogen provided a good fit for all data. More recently, Greenhalgh and Runcie (1962) found no statistical difference between local regressions derived for different cuts of the same sward. Can Dr Minson suggest how these contradictions may be resolved?

DR MINSON: The regression equation calculated by Lancaster (1954) had a 0.1% coefficient of variation. Since no cutting dates are given, it is not possible to test whether the data are homogeneous or made up of separate equations for different times of the year. In the Hurley work, different herbage species did not give different faecal nitrogen regression equations. It would be wrong to assume that equations derived at one centre will automatically apply in a different environment and equations should always be developed locally. Differences in climate and sward management are two possible reasons for the apparent discrepancy between various centres studying faecal nitrogen relationships.

DR A. H. CARTER: Emphasis in Ruakura intake studies has been on the feed/faeces ratio rather than digestibility, to which it is of course related. The feed/faeces ratio, in fact, showed a more nearly linear relationship with faecal nitrogen. Our approach has been an essentially empirical one, the problem being that of best predicting feed/faeces ratio from certain faecal components. The great convenience of a linear regression justifies transformation of the variables if necessary. It is not necessary nor even highly likely, however, that there should be an exact linear underlying relationship. Dr Minson is right in emphasizing the need to indicate the accuracy of predicted values. However, distinction must be drawn between random errors on the one hand and biases on the other. The former, due largely to technical factors and animal variability, can be minimized by increasing the number of observations. Biases due primarily to inadequacy of the basic regression model, cannot be so reduced and pose serious problems, as exemplified by the concept of "local" regressions.